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ANALYTICAL INVESTIGATIONS OF BULK WAVE RESONATORS IN
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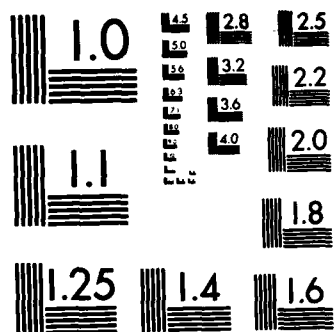
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Annual Report on Analytical Investigations
of Bulk Wave Resonators in the Piezoelectric Thin
Film on Gallium-Arsenide Configuration

Harry F. Tiersten

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19. ABSTRACT (Continue on reverse if necessary and identify by block number) The results of earlier calculations of the quality factor of the piezoelectric thin film on semiconductor composite resonator due to radiation into the semiconductor wafer for the strip case both when trapping is and is not present are briefly discussed. Experimental verification of the results is noted. It is also noted that the direct calculation procedure is extremely cumbersome to use, but that it is required to check the accuracy of a perturbation procedure which is much easier to use. The perturbation procedure for the calculation of the quality factor of the composite resonator due to radiation into the semiconductor wafer is discussed and it is noted that the perturbation procedure enables calculations for the case of rectangular electrodes and diaphragms to be performed. It is further noted that for the strip case the calculations of the quality factor using the perturbation procedure are in good agreement with the results obtained from the earlier more cumbersome direct procedure.					
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11. Analytical Investigations of Bulk Wave Resonators in the Piezoelectric Thin Film on Gallium-Arsenide Configuration
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In the previous annual report a description of the composite resonator was provided and it was noted that the values of the material constants of aluminum-nitride was open to some question. In addition, an explanation of the meaning of the words "energy trapping" was presented and the importance of its existence in high Q composite resonators was noted. It was also pointed out that the fundamental essentially thickness-extensional mode will never trap for an aluminum-nitride film on a flat gallium-arsenide plate, but that the second mode will trap for the same composite flat plate for any ratio of film-thickness to diaphragm-thickness. This was subsequently verified experimentally at Westinghouse Defense and Electronics Center.

In the previous report a somewhat detailed discussion of an analysis of the composite resonator driven by a voltage applied across strip electrodes and including radiation into the bulk semiconductor was given. In short, the calculations based on that analysis showed that when trapping is not present the Q is a very rapidly varying function of the ratio of the composite resonator thickness to the wafer thickness and that the range of variation is very large, but that when trapping is present the Q is always much larger and its range of variation much smaller than when trapping is not present. This relative stability and instability in Q when trapping is and is not present is what was observed at Westinghouse. A brief paper based on this work has been published¹ and a more comprehensive paper detailing the same work will be published² in October. This type of calculation is extremely cumbersome to perform and is preliminary to constructing a perturbation theory to calculate the Q due to radiation into the bulk semiconductor, which is much easier to use. The more cumbersome direct calculation is required in order to check the accuracy of the perturbation calculation.

Currently, a perturbation analysis of the Q due to radiation into the

semiconductor wafer is being performed. This analysis is considerably less cumbersome to use than the earlier direct variational treatment^{1,2} and is not restricted to the case of strip electrodes and diaphragms. In the treatment the resonant mode of interest is determined from the equation for transversely varying essentially thickness-extensional modes in composite resonators³ and simple approximate but very accurate conditions at the edge of the diaphragm. This resonant mode is then used to determine the radiation into the semiconductor wafer by means of a variational approximation procedure. Then the resonant mode and the radiation field are employed in a perturbation integral to calculate the Q. In this work only the configuration in which the film continues to the edges of the etched diaphragm is considered both when trapping is and is not present. However, now, of course, the cases of rectangular electrodes and diaphragms are being considered.

Of course, as in the earlier work^{1,2}, all radiating plate waves in the thick region of the gallium-arsenide must be included to achieve accuracy. Calculations utilizing the perturbation procedure have been performed for the case of strip electrodes for the same definitive geometries considered in the earlier work^{1,2}. These geometries consist of wafer thicknesses ranging from 4 mils to 8 mils and a film thickness of 7 microns and diaphragm thickness of 14 microns. Although different lateral dimensions were considered in this work, for the strip case for comparison with the earlier work a diaphragm width of 500 microns was used when trapping is not present and 600, when trapping is present. The calculated results for the strip case are in good agreement with the earlier more cumbersome direct calculations^{1,2}. When trapping is not present the highest Q's calculated are very nearly the same as those obtained in the earlier direct calculation^{1,2}, but the lowest Q's calculated by means of

the perturbation procedure tend to be nearly an order of magnitude higher than those calculated by the earlier direct procedure^{1,2}. We are not absolutely sure of the reason for this discrepancy, but there are two possibilities. The perturbation procedure might be tending to lose its accuracy for low Q because of the increased radiation or the resonant frequency might not have been sufficiently precisely determined by means of the earlier direct procedure^{1,2} for the accurate determination of the lowest Q values. The location of the peaks and valleys of Q with wafer thickness determined by means of the perturbation procedure is in quite good agreement with those obtained from the earlier direct calculation. When trapping is present the Q's calculated by means of the perturbation procedure are in very good agreement with those obtained from the earlier treatment. For the case of rectangular electrodes and diaphragms, the analysis has been completed and the programs have been written, but no results are as yet available.

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1. D. S. Steven, H. F. Tiersten and D. V. Shick, "On the Reduction in Quality Factor of the Piezoelectric Thin Film on Semiconductor Composite Resonator Due to Radiation into the Bulk Semiconductor," 1985 Ultrasonics Symposium Proceedings, IEEE Cat. No. 85 CH2209-5, Institute of Electrical and Electronics Engineers, New York (1985), p. 311.
2. D. V. Shick, D. S. Stevens and H. F. Tiersten, "Quality Factor of the Piezoelectric Thin Film on Semiconductor Composite Resonator Resulting from Radiation into the Semiconductor Wafer," to be published in the Journal of Applied Physics (October, 1986).
3. H. F. Tiersten and D. S. Stevens, "An Analysis of Thickness-Extensional Trapped Energy Resonant Device Structures with Rectangular Electrodes in the Piezoelectric Thin Film on Silicon Configuration," J. Appl. Phys. 54, 5893 (1983).

A talk entitled "A Perturbation Calculation of the Quality Factor of the Piezoelectric Thin Film on Semiconductor Composite Resonator Due to Radiation into the Wafer" by D. V. Shick and H. F. Tiersten is to be presented at the upcoming 1986 Ultrasonics Symposium in mid-November. A paper with the same title is to be published in the 1986 Ultrasonics Symposium Proceedings. The abstract of the talk is appended to this report.

Publications

"On the Reduction in Quality Factor of the Piezoelectric Thin Film on Semiconductor Composite Resonator Due to Radiation into the Bulk Semiconductor," D. S. Stevens, H. F. Tiersten and D. V. Shick, 1985 Ultrasonics Symposium Proceedings, IEEE Catalog Number 85 CH2209-5, Institute of Electrical and Electronics Engineers, New York, 311-318 (1985).

"Quality Factor of the Piezoelectric Thin Film on Semiconductor Composite Resonator Resulting from Radiation into the Semiconductor Wafer," D. V. Shick, D. S. Stevens and H. F. Tiersten, to be published in the Journal of Applied Physics (October, 1986).

A PERTURBATION CALCULATION OF THE QUALITY FACTOR OF THE
PIEZOELECTRIC THIN FILM ON SEMICONDUCTOR COMPOSITE
RESONATOR DUE TO RADIATION INTO THE WAFER*

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In a recent analysis of the piezoelectric thin film on semiconductor composite resonator vibrating in an essentially thickness-extensional mode it was shown that the quality factor (Q) due to radiation into the bulk semiconductor is a very sharply varying function of the ratio of the thickness of the resonator to that of the film if trapping is not present, but not if trapping is present. The treatment employs a very accurate but extremely cumbersome variational approximation technique and is restricted to the case of strip electrodes and diaphragms. In this work a perturbation analysis of the Q due to radiation into the semiconductor wafer is presented, which is considerably less cumbersome to use than the earlier variational treatment and is not restricted to the case of strip electrodes and diaphragms. In the treatment the resonant mode of interest is determined from the equation for transversely varying essentially thickness-extensional modes in composite resonators and simple approximate but very accurate conditions at the edge of the diaphragm, from which the radiation into the wafer is determined by means of a variational approximation procedure. Then the resonant mode and the radiation field are employed in a perturbation integral to calculate the Q . For the case of strip electrodes and diaphragms the calculated results are shown to be in good agreement with the earlier more cumbersome calculations. In addition, it is shown that the perturbation calculations are readily performed for the case of rectangular electrodes and diaphragms.

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